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ASSEMBLY VS. DIRECT LAUNCH OF TRANSFER VEHICLES

Stephen J. Katzberg
E. Brian Pritchard

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LIST OF ACRONYMS
TM—102686

HLLV	Heavy Lift Launch Vehicle
LEV	Lunar Excursion Vehicle
LTV	Lunar Transfer Vehicle
MEV	Mars Excursion Vehicle
MTV	Mars Transfer Vehicle
IMLEO	Initial Mass in Low Earth Orbit
MHLLV/SDV	Mars HLLV/Shuttle Derived Vehicle
ALS	Advanced Launch System
LEM	Lunar Excursion Module
CSM	Command Service Module
ET	External Tank
ORU	Orbital Replaceable Unit
EVA	Extra Vehicular Activity
IVA	Intra-Vehicular Activity
SEI	Space Exploration Initiative

Introduction

The purpose of the overall study is to investigate launching the Lunar or Mars space transportation vehicles direct into low earth orbit, requiring no on-orbit assembly, versus launching vehicles partially assembled and integrating them at either Space station or an alternate node.

The issue to be investigated is operations' requirements at each block step of HLLV capability. In principle, the greater size should reduce the number of operations on-orbit. However, it is to be expected that the larger and, consequently, highly complex HLLV's will have associated with them increasing degrees of required ground support and operations, as well as increasing degrees of required built in redundancy and end-to-end self-test. Reliability concerns will grow, since the complexity of the vehicle and the rigors of the launch environment could make the probability of system failure more likely.

The major division is between one large spacecraft direct-to-moon or direct-to-Mars and any on-orbit assembly regardless of where on-orbit the assembly is done. Within the on-orbit assembly option, the secondary question will be addressed as to what are the issues that would drive toward the development of an alternative to Space Station Freedom as the assembly node.

Assumptions

In developing the requirements for on-orbit assembly operations, with or without using Space Station Freedom, the Option V content will be used. The requirements for Option V Lunar IMLEO (LTV/LEV using the Aerobrake) are approximately 160 t, with 4 tanks of approximately 26 t per wet tank, plus the LEV of 32.2 t, and the LTV Core of 22.1 t.

The required Mars vehicle IMLEO depends on the exact mission, e.g. manned-opposition (781 t), manned-conjunction (666 t), or cargo (581 t.)

The reference set of Earth-to-Orbit transportation options (appended as an attachment) offers a range of LEO payloads starting from the current expendables up to 20 t for Shuttle, through proposed Shuttle C at around 70 t to Hybrid Shuttle Derived Vehicles at around 100 t up through 140 t for MHLLV/SDV-ALS/3 Booster ALS and on to External Tank Derived configurations or 4 Booster ALS of near 200 t ending up at 225 t for the 3 ET Booster and ET 3rd Stage core.

It is worth observing here that the Saturn V had a 120 t capacity to 100 nm low earth orbit, and that in the docking operations of LEM and CSM, an electrical umbilical was the only utility interconnect

Vehicle/Assembly Requirements Taxonomy

There exist some major option paths that help to organize the assessment of direct launch vs. on-orbit (Space Station or other transportation node) assembly and including manned vs. unmanned.

I. Direct Launch

The simplest over-all division applies to whether or not, and which SEI missions could be supported by a single, direct-launch vehicle.Since the total IMLEO for the Lunar vehicles is 160 t, with a slight reduction for the cargo configuration, it can be seen that none of the Shuttle derived vehicles or ALS options could support the LTV/LEV. Since LTV/LEV baseline uses Aerobraking, other, all propulsive approaches to this vehicle would require even larger ETO. Only the Option "External Tank Core with triple External Tank Booster" or larger variants could support the LTV/LEV required IMLEO. It should be noted that the bulk of LTV/LEV IMLEO comes from propellant, and even significant modifications to the vehicle design will not impact this dominant fact.

For the Mars vehicles, there are no ETO systems proposed that can support any of the vehicles for direct launch.

However, it is important to note that the transfer of some important payload to the Moon and Mars could be done with expendable vehicles. For example, the Option 1 Manifest calls for robotic off-loaders and hab. modules in the 10 t range as the bulk of the earlier cargo flights. It is also true that individual elements of the LTV/LEV or MTV/MEV could be carried intact by several ETO options, but assembly would be required which is excluded in this option.

II. Pieces in Orbit

All the next options in the taxonomy represent a quantum jump from the direct launch option. Assembly on-orbit requires, by definition here, a transportation node. A transportation node can be nothing more than a rendezvous point or it can be a real physical facility, more or less complicated, dedicated to just assembly and operations or multipurpose, such as the Space Station.

Available supporting resources on-orbit vary from none at a rendezvous point to IVA and EVA astronauts plus teleoperation and robotics, simple repair equipment, ORU's, power, sensors, thermal, mechanical/structural, etc., at a man-tended or permanently manned physical transportation node or Space Station Freedom.

Pieces in orbit imply varying degrees of required support equipment and facilities on orbit, a greater amount of on-orbit subsystem/system verification support, a sophistication in ORU concept, design, and logistics philosophy and high confidence in on-orbit operations.

By way of compensation, there is a lessening of required direct ground end-to-end verification, many more options for ETO approaches, including international and commercial, the possibility of constructive intervention, a mix of non-man rated cargo vehicles transporting man-rated components, etc.

II.A--Large Pieces

It is clear that if the LTV/LEV and MTV/MEV are in small enough pieces, they can be brought up to the transportation node for assembly into the required vehicle. Thus, as is shown in the attached listing of Lunar and Mars vehicle constituent subelements, the largest MTV/MEV element is the 33 t Mars Transfer Crew Module & Equipment, while for the LTV/LEV the largest element is 15 t.

As far as the capacity of ETO systems to bring these elements to orbit is concerned, virtually any of the proposed Shuttle derived vehicles will be sufficient. Perhaps even current expendables (ELV's) and Shuttle itself would suffice. Nevertheless, current NSTS or ELV capabilities will not support the current Option I (Option V) as stated.

II.B--Small Pieces

The case of small pieces is one in which the LTV/LEV or MTV/MEV is assembled from small elements. In this scenario, current launch vehicles would be sufficient to launch virtually everything needed. Via EVA/IVA plus robotics or teleoperation, in a mix or match, the LTV/LEV or MTV/MEV would be assembled. Obviously, this approach would be a major challenge for EVA/IVA and telerobotics, and would require a massive effort in ORU technology and an aggressive, enforced commonality program policy. In addition, techniques for augmenting man's capabilities from the ground would be required.

On the plus side, the ETO options would increase dramatically to the maximum level. Many simple orbit-on-demand options, replete with multiple combinations would be available for logistical support. While on-orbit operations would be expensive cost-to-orbit, especially initial cost could be expected to be greatly reduced.

Required Operations

Class I.-Direct Launch

Since it has been pointed out that direct launch of the Option V (or Option I) LTV/LEV or the MTV/MEV would not be possible with this option, it is necessary to consider only the expendables in direct launch. Since most current and simple development expendables have small capacity to Lunar surface and smaller capacity to Mars, some on-orbit assembly of expendables would provide the ability to bring to the Lunar surface larger elements of the human support infrastructure. The negative impact of this approach is the required assembly at the transportation node of the vehicle.

The vehicles to be assembled would be very few since the interconnection of a very few major elements would be sufficient to carry all the necessary large surface systems. Moreover, the vehicles assembled would not be man-rated and hence the verification of the final vehicle would be the least severe.

Assembly would consist of activating Apollo-like mechanical attachment of upper stages as subsystems with the necessary integral electro-photonic interconnects to enable unified GN&C and Communication. Fluid couplings would probably not be needed to support expendable cargo flights.

Class II.-Pieces in Orbit

Subclass II.A-Large Pieces

Vehicle Design

Assembly of the LTV/LEV and MTV/MEV in this class would represent the closest to a pure Option I/Option V case. Vehicle elements of the largest possible size consistent with the ETO transportation system would be integrated. The term "integrate" will be used rather than "assemble" to denote the putting-together of large, more-or-less stand alone subsystems.

Each subsystem would be functionally verified on the ground as much as possible, launched, integrated and then both reverified and end-to-end flight vehicle validated on-orbit. Thus, the subsystems would require internal self-checking and built-in test equipment appropriate to that subsystem.

Man Rated vs. Non-Man Rated

The integration and flight certification of non-man rated cargo vehicles would be somewhat easier than would be the case for man rated.

ETO

The requisite vehicles to support the II.A approach could be drawn from a larger set than in direct launch. Largest ETO vehicle would be required to bring up the largest fully loaded subsystem. (In almost all cases, the vehicle dry weight represents only a small proportion of propellent.) Smaller subsystems could be apportioned to other available launch vehicles: government, commercial, international, etc., for maximum access/minimum cost.

On-Orbit Facilities/Operations

Required on-orbit support equipment would be a large scale manipulator, support structure, and access, via communication link, to ground support verification data systems, inspection sensors and some minor degree of EVA/IVA support.

ORU/Mission Success Enhancements

ORU support would be limited to replacement of block subsystems, and hence on-orbit mission intervention would be possible. Subsystems with least reliability, but available via orbit-on-demand, could result in significant improvement of end-to-end mission success probability.

Subclass II.B-Small Pieces

Vehicle Design

In this subclass, the vehicles would consist of a number of (high degree of commonality) parts that are assembled into the desired combination of Lunar or Mars transfer vehicles. Considerable interfaces, electrical, fluid, mechanical, would have to occur. Simple interface design would be at a high premium. Considerable testing could occur on each small subsystem before launch. On the other hand, with the effort at simple design to help control on-orbit assembly complexity comes an overhead: Convenience of interface would imply, possibly in a major way, a lack of efficiency or compactness of design.

It is also the case that some elements cannot be reduced below a certain point--propellent being the prime example.

Man Rated vs. Non-Man Rated

In this option the on-orbit assembly of man-rated vehicles and their flight certification would be the most difficult.

ETO

The Earth-to-Orbit impact of this approach would be very beneficial. Since the elements are by definition small, virtually any current expendable launch vehicle could be utilized to carry important parts to orbit. The role of commercial participation could be expected to grow, particularly in regard to launch vehicles. Considerable cost savings could occur. However, a considerable "space traffic control" issue might be encountered. Linking up with a transportation node, virtual or otherwise, would be straightforward but would require tight coordination.

On-Orbit Facilities/Operations

Facilities impacts for this approach would be the greatest. Not only large space cranes and rigid holding structures would be needed, but EVA/IVA would be heavily utilized. Since EVA/IVA could easily be swamped, reliance would have to be placed on teleoperation and robotics. Many teleoperation activities might mean that ground operators would be required. Since TDRSS represents a time delay far in excess of that tolerable by closed-loop master-slave teleoperation, a low latency ground-to-space data network might be the only solution. True robotics is virtually non-existent, mostly at the conceptual stage or at the crudest functional level.

ORU/Mission Success Enhancements

The availability of "bite-sized" on-orbit subsystems (small ORU's) obviously enables EVA/Telerobotics intervention and implies a considerable enhancement of the probability of successful launch in the presence of identifiable subsystem malfunction. In principle, the nursing of the spacecraft up until launch represents a continuation, and at a lower activity level, of EVA/IVA/Telerobotics already in operation.

In addition, the "small pieces"/ORU's approach yields the maximum availability of available launch services, world-wide, and multiple second source on the ORU's. Simple interface design (albeit with the attendant hardware, mass, interface, etc. overhead) would permit any number of companies to provide (sub)functional elements, man-rated or otherwise, given the company commitment to space-qualifying the ORU at the (sub)system level. Inventory, logistics, and launch traffic control would be more severe than for the large pieces.

Minimizing the Amount of On-Orbit Assembly

In overview of the foregoing, it seems clear that on the one hand the "small pieces" will overload the available EVA resources. If the infrastructure can be established for teleoperations (the most effective form of telerobotics and the best hope for near term application to man rated spacecraft) then the "small pieces" just comes barely into the realm of believability.

At the other extreme, the single vehicle approach, within the Option V or Option I scenarios seems equally impractical due to the considerable development required to create the ETO capability. Moreover, such large (>120 t Saturn V IMLEO capacity) and complex vehicles would require levels of ground Verification and Validation that have never been approached before in space flight. If the Shuttle is any indicator of expected reliability and adherence to flight schedule at the 20 t to orbit level, the required 160 t for LTV/LEV would be expected to yield schedule performance jeopardizing continual Lunar operations. Cargo operations are definitely possible, consistent with the Option V/Option I Scenarios Lunar Elements, while for even the cargo vehicle the Mars Scenarios cannot be supported (581 t.)

Thus, minimizing on-orbit operations within the Option V or Option I begins with rejecting the direct launch of a full sized vehicle. Integrating or assembling vehicles within the orbital capability of astronauts and telerobotics is consistent with reasonable expectations for near future ETO capability. Larger vehicle elements require less operations, but this must be traded against mission reliability enhancement resulting from an aggressive ORU philosophy and EVA intervention.

Space Station vs. Alternate Transportation Node

Support facilities (structure, power, thermal rejection) will exist at the Space Station, including the FTS, the SSRMS, and the MSC. For any but the largest subsystems integration, all such support will be needed, and it is difficult to see what justification there would be in a second transportation node when one already exists.

If it is an issue of impact on Space Station of SEI operations, say for example in the area of materials processing, studies have shown that the SEI operations consist of considerable periods of inactivity with minimal modification of the low-g environment.

Further, if low-g materials processing is demonstrated to be what it is hoped, then the establishment of a true micro-g co-orbiting free-flyer would be a logical solution.

Conclusions

It should be noted that even for the LTV/LEV direct launch possibility the ETO system based on Shuttle C represents a system with 50 per cent more required IMLEO capacity than the Saturn V. For the Mars Missions, the required IMLEO ranges from 550 t to over 770 t. Even with the much larger ALS or Eternal Tank-derived vehicles (up to 250 t IMLEO) some assembly is required, while the reality of such launch systems is limited to the conjectural.

Thus, it would seem that even to support the more leisurely Option V schedule, let alone more aggressive schedules from Option I, or other future scenarios, assembly will be required. It seems difficult to credit the idea of developing a separate transportation node other than Space Station with its already available power, thermal, DMS, EVA/IVA/Telerobotics, etc. resources. Issues of interference with materials processing have been shown to be avoidable. Concern over interference with science investigations should be balanced with the ease with which the severely impacted could inexpensively become free-flyers. With this understanding, the issue becomes more of a "mix-or-match" between the "small pieces in orbit" and the "large pieces in orbit" approaches.

The smaller the pieces (ORU's) the more opportunities for constructive mission intervention and the broader range of support sources (commercial second source, commercial-international launch services) at the expense of cost and complexity of on-orbit operations. The larger the pieces, the less on orbit operations, but less opportunity for diverse launch services, second sources, or constructive intervention or spares.

At this stage in architecture development, the trade studies necessary to generate discriminators on the optimum set or size of ORU's are at a granularity unwarranted by the maturity of the architectures.

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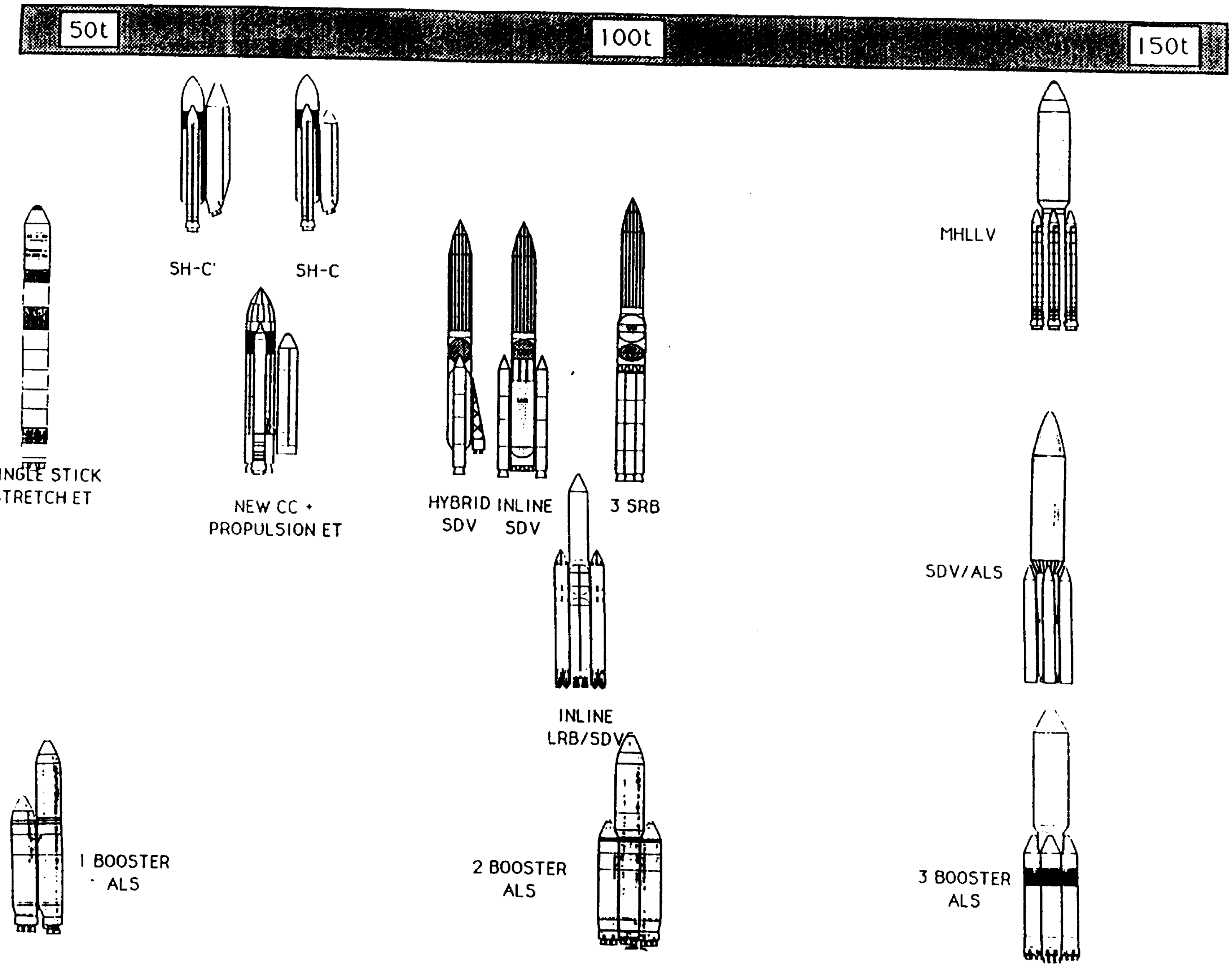
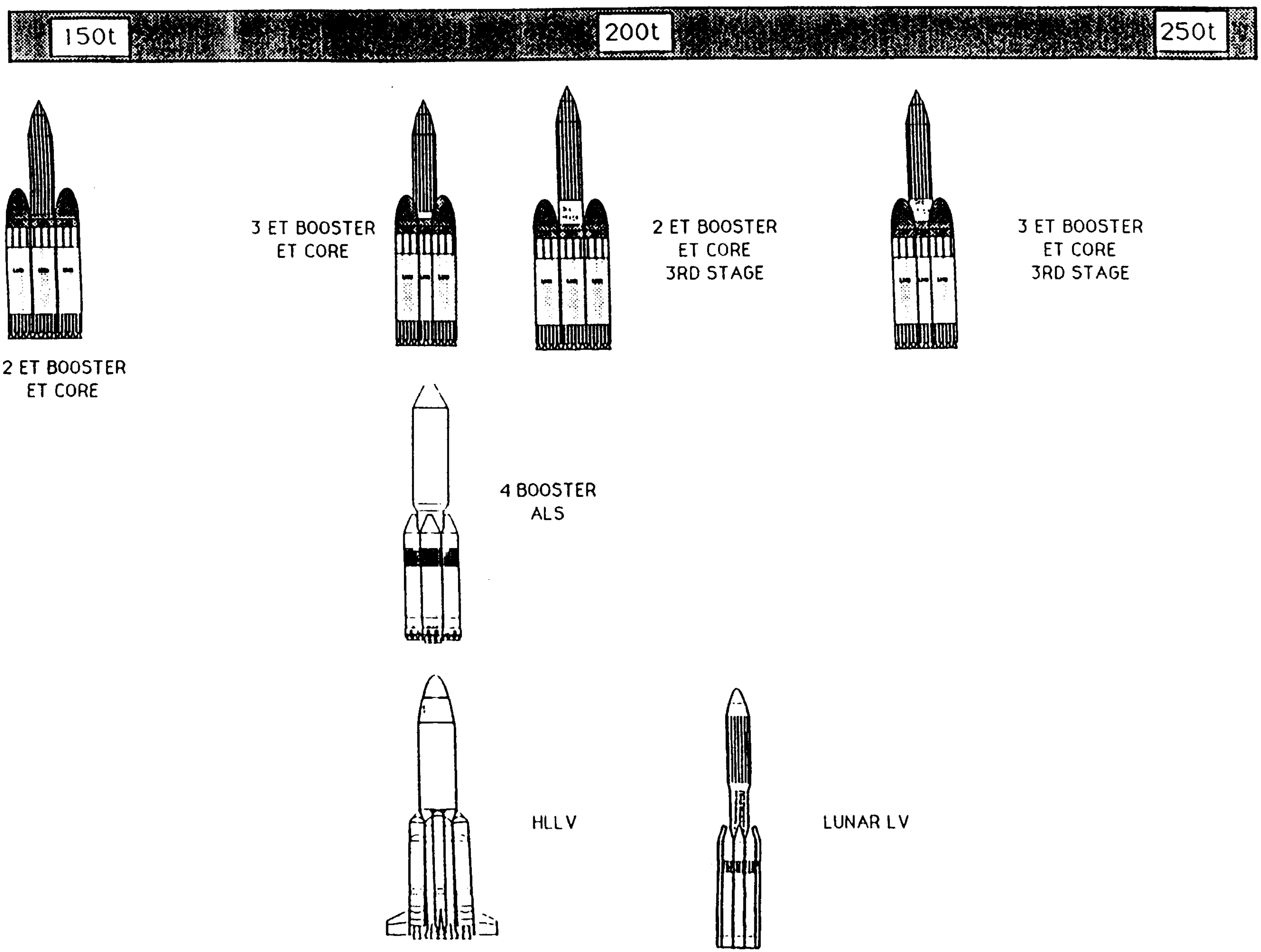
EARTH-TO-ORBIT TRANSPORTATION

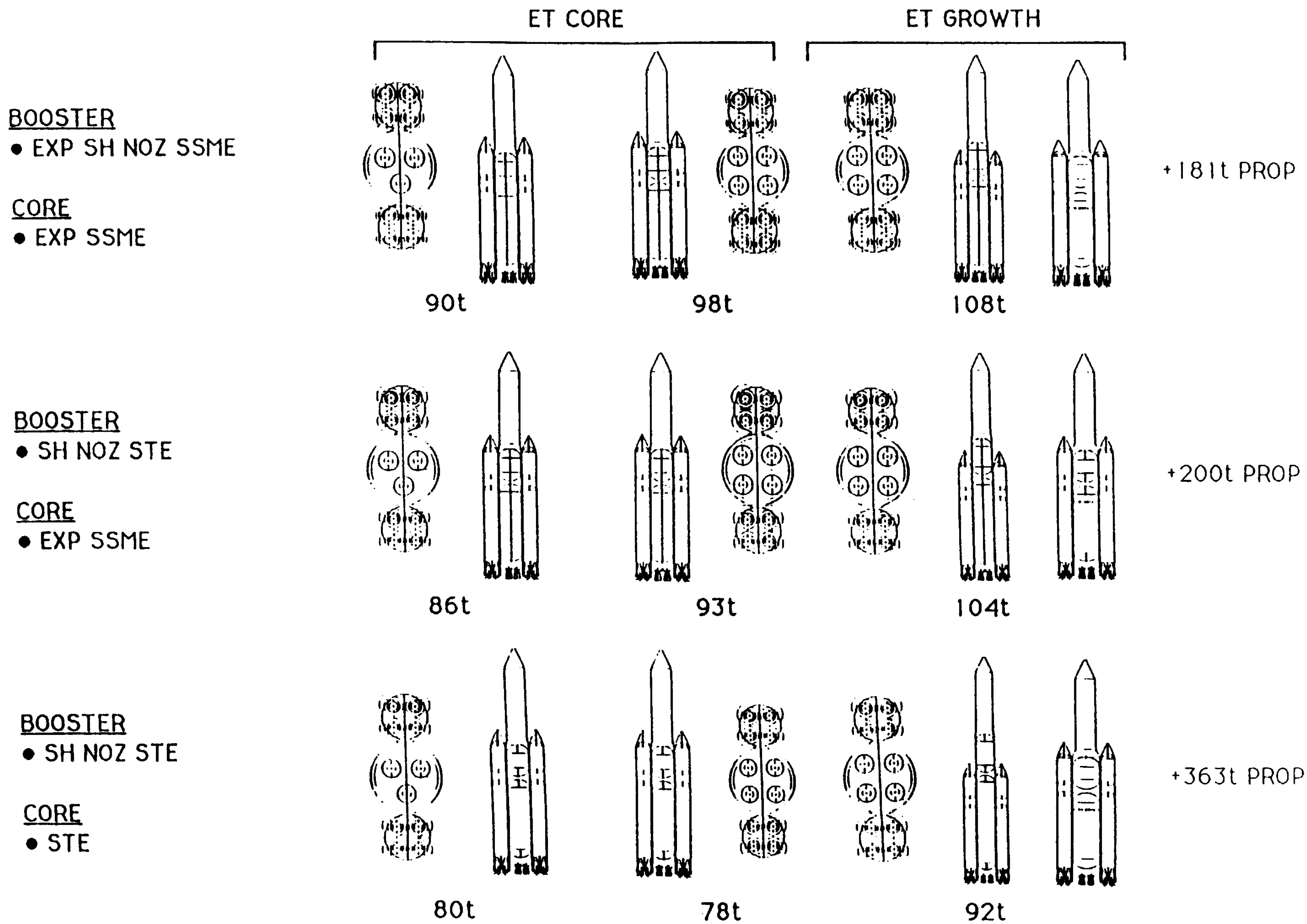
UNMANNED ETO CONCEPTS



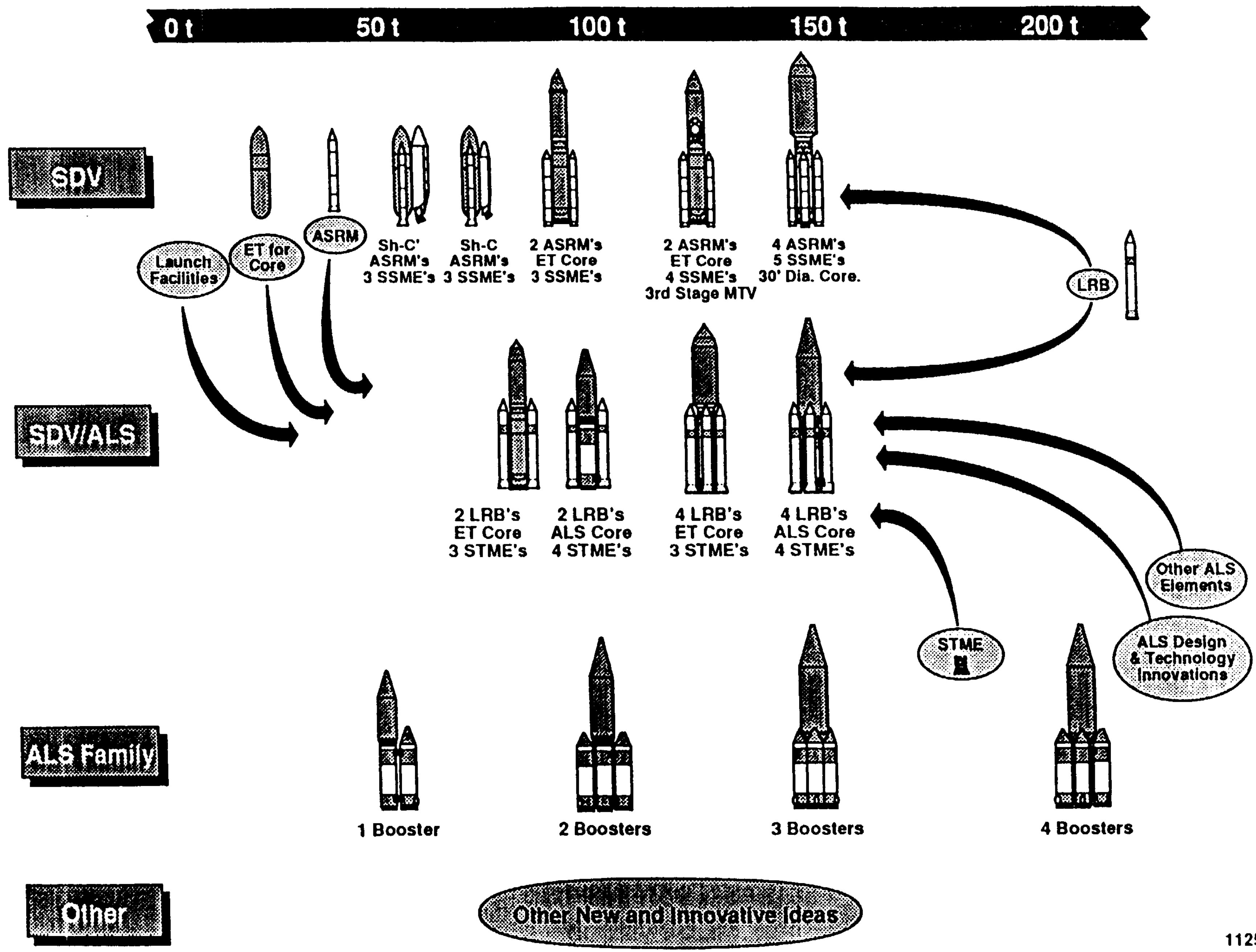
UNMANNED ETO CONCEPTS



LRB/SDV OPTIONS

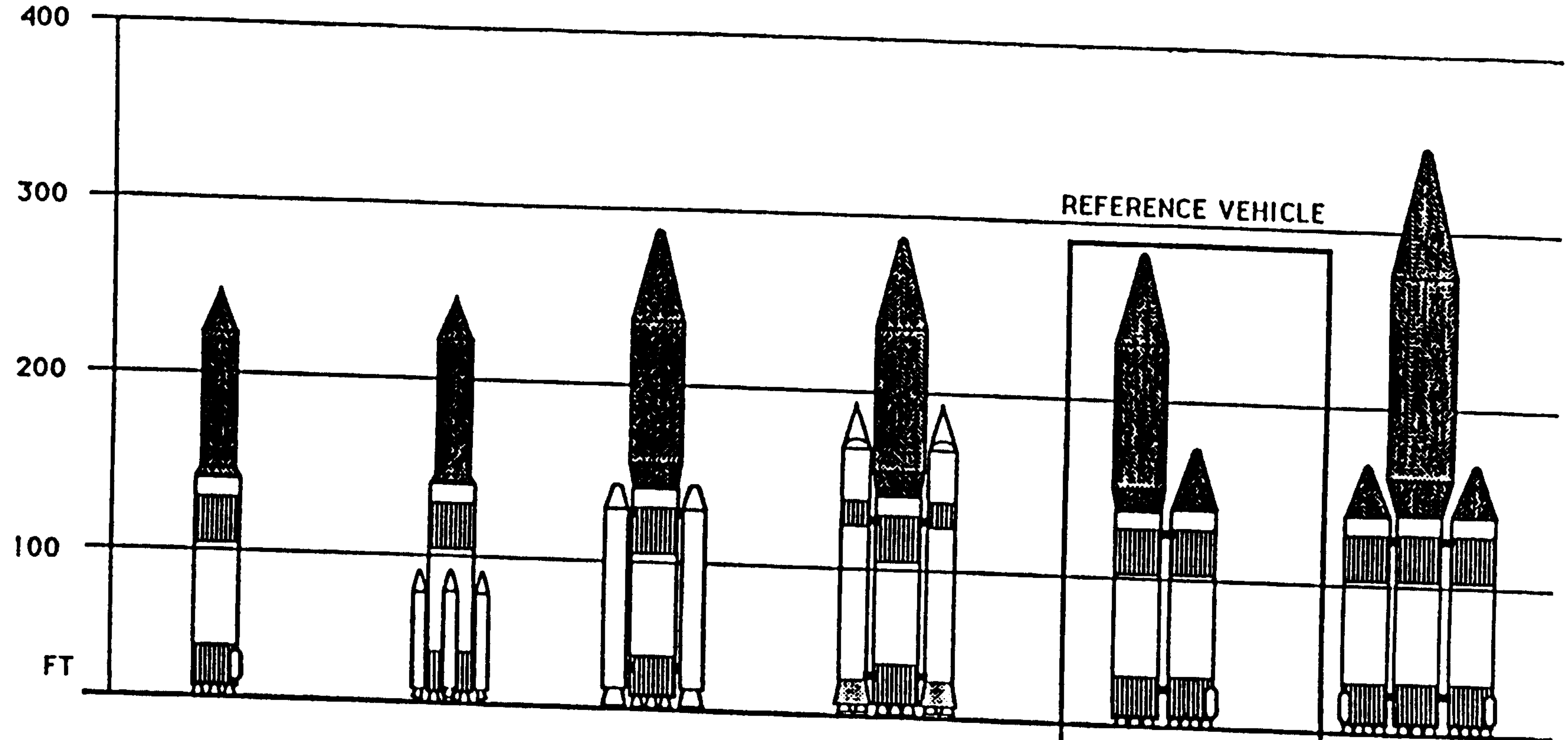


SEI Candidate Unmanned Vehicles



1125

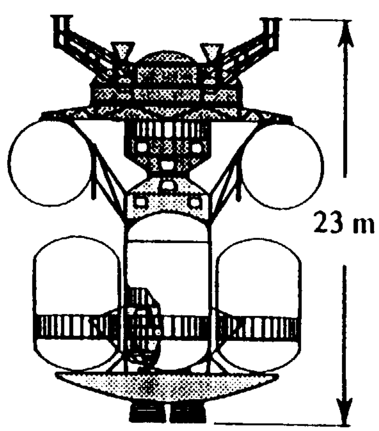
THE ALS FAMILY



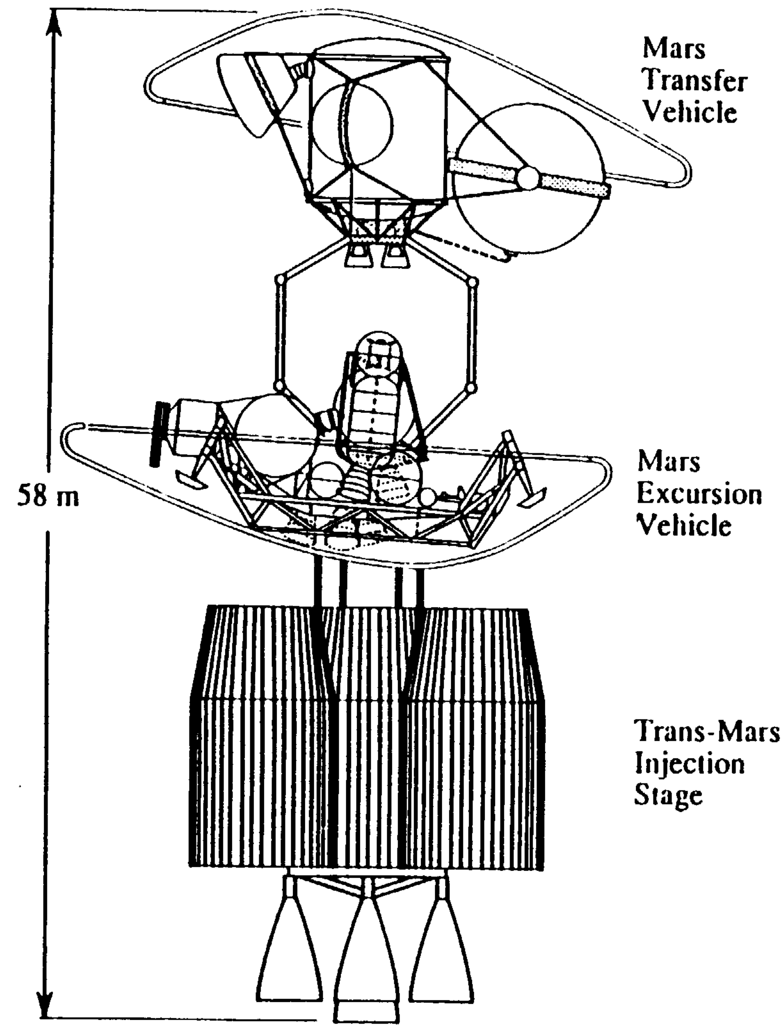
RATED PAYLOAD	40 - 80 KLB	40 - 80 KLB	80 - 110 KLB	100 - 251 KLB	80 - 120 KLB	120 - 300KLB
BOOSTER TYPE	STAGE & HALF	ALS - SRM	SRMU	STS LRB	ALS LRB	ALS LRB
BOOSTER PROP.	LO2 / LH2	SOLID	SOLID	LO2 / LH2	LO2 / LH2	LO2 / LH2
OF BOOSTERS	N / A	3 - 8	2 - 4	2 - 6	1	2 - 4

FIG 3 - 1

Comparison of Lunar & Mars Transfer Vehicles

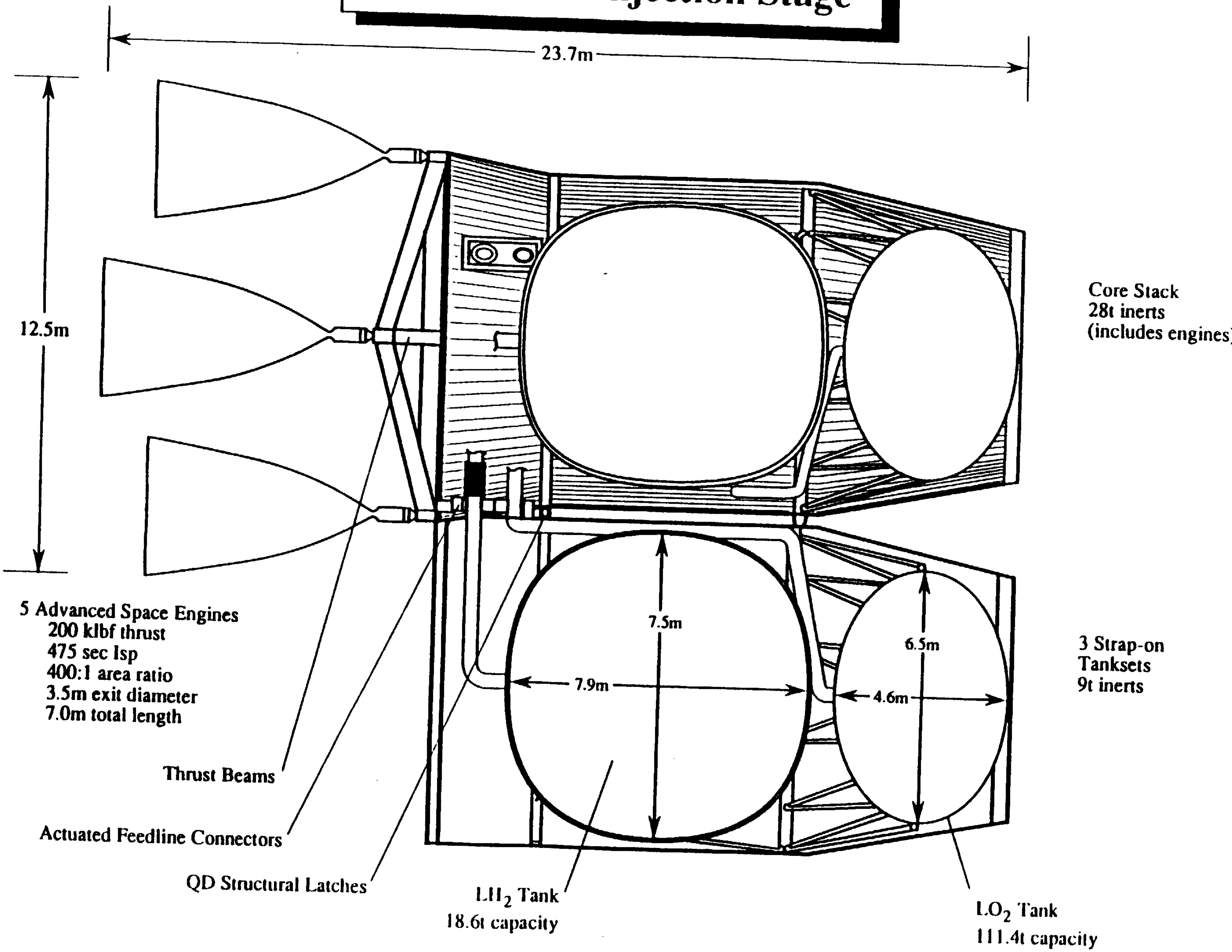


Lunar Transportation System
Mass = 172t



Mars Transportation System
Mass = 730t

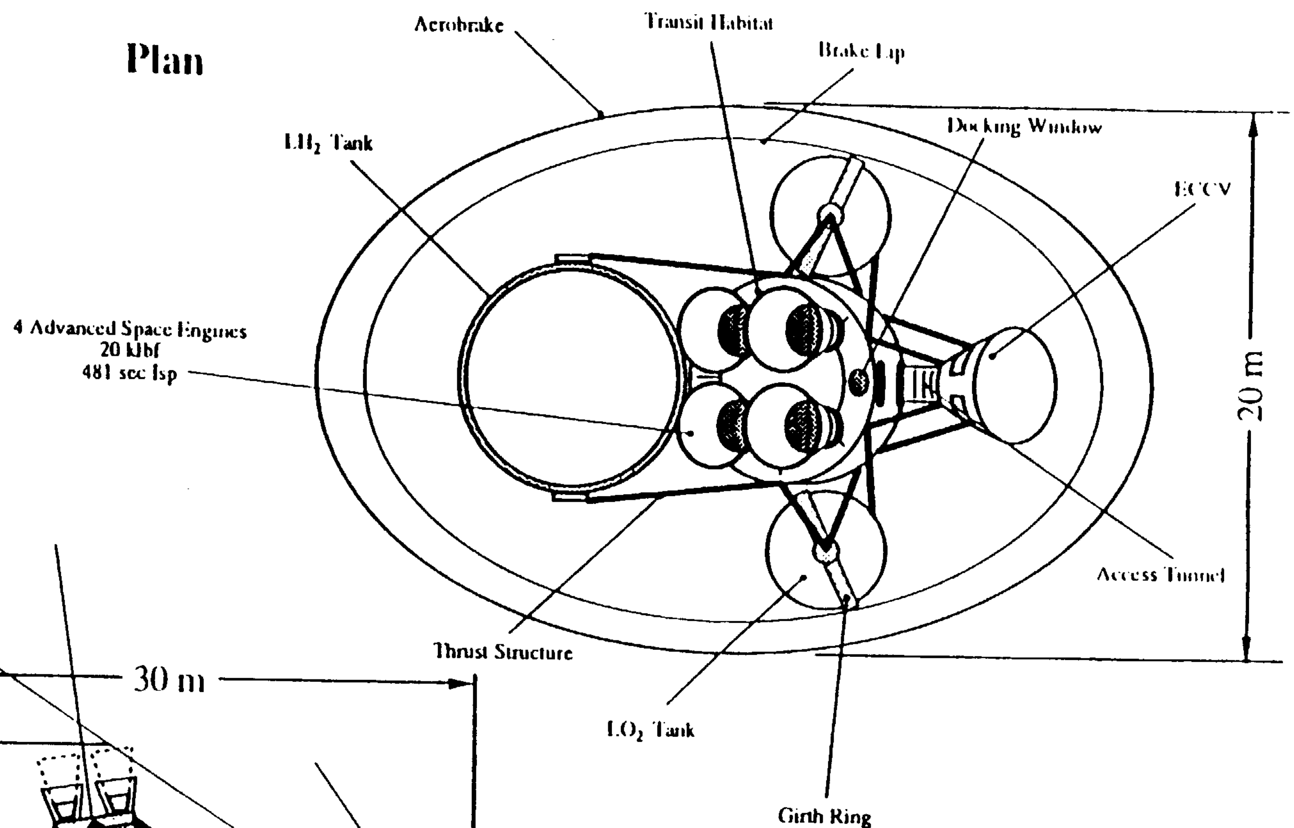
Trans Mars Injection Stage

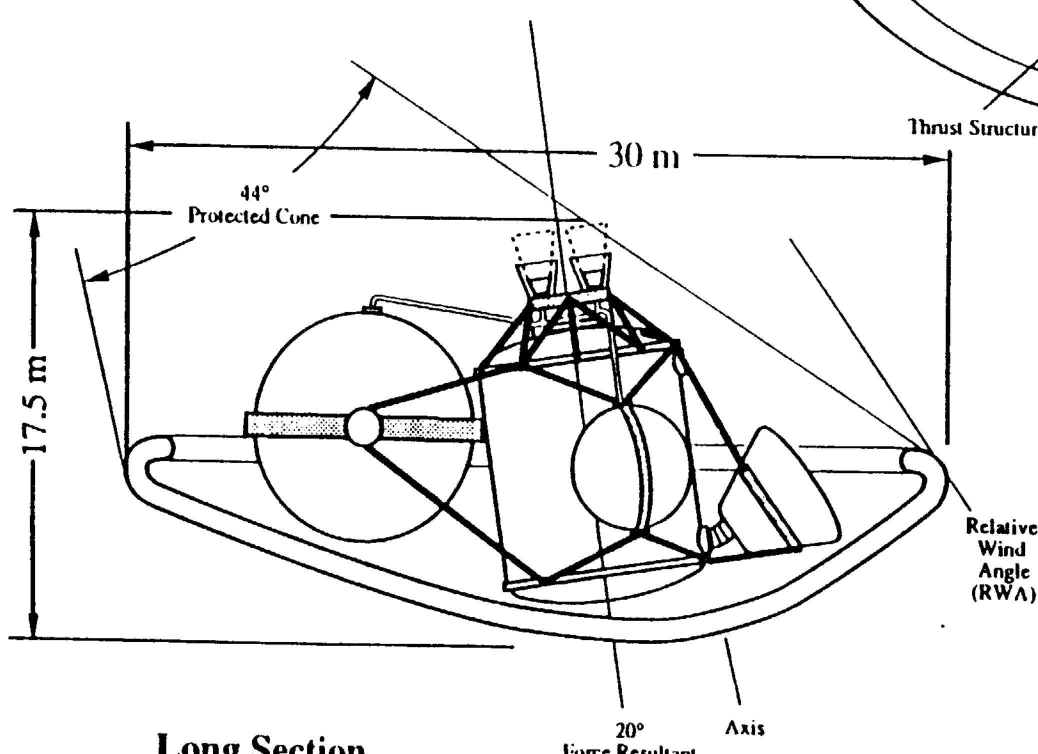


Mars Transfer Ve. 'le (MTV)

Crew System	41.0 t
ECCV	7.5 t
Aerobrake	20.7 t
TEIS	84.5 t
Total MTV	**153.7 t**

Plan

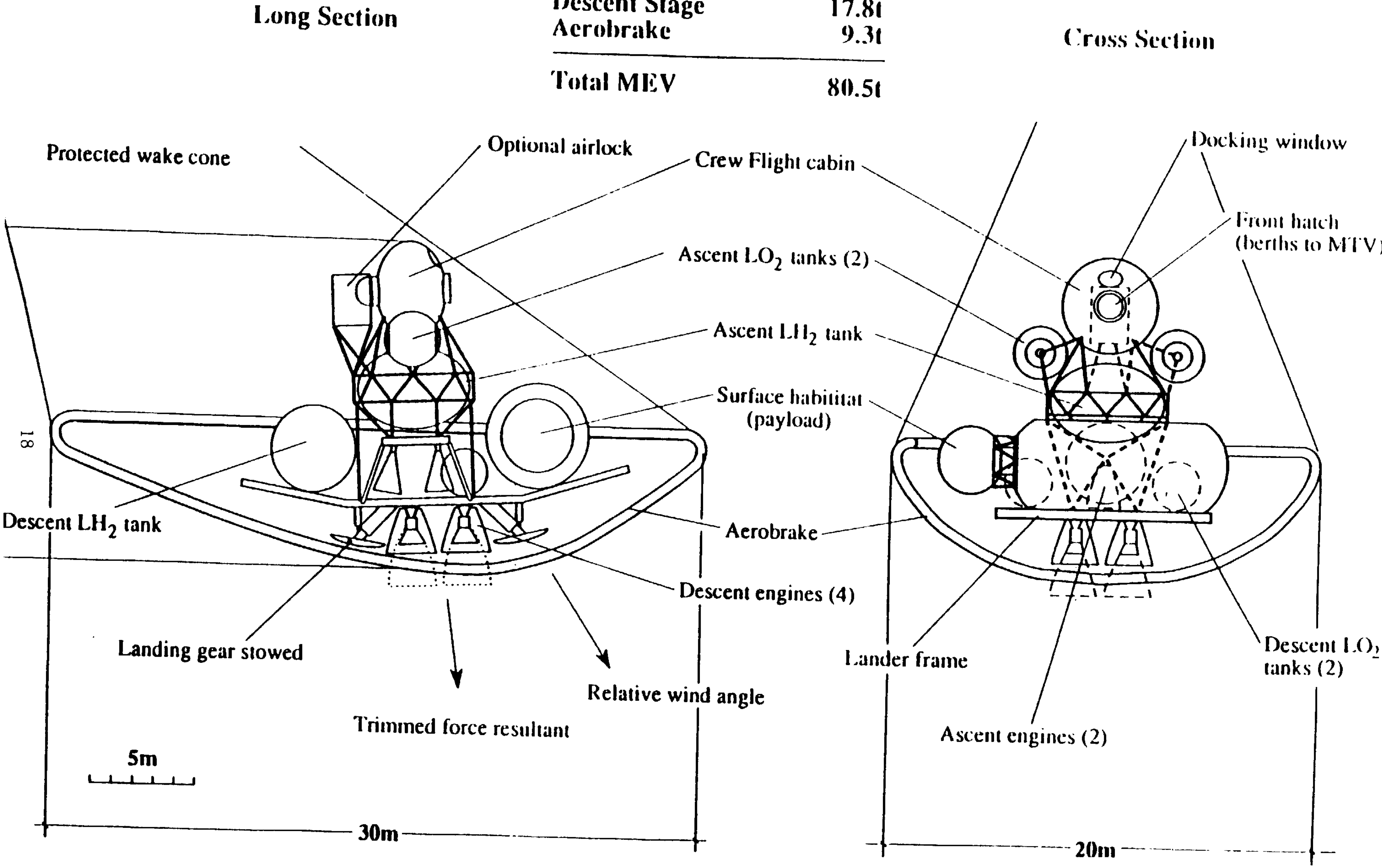


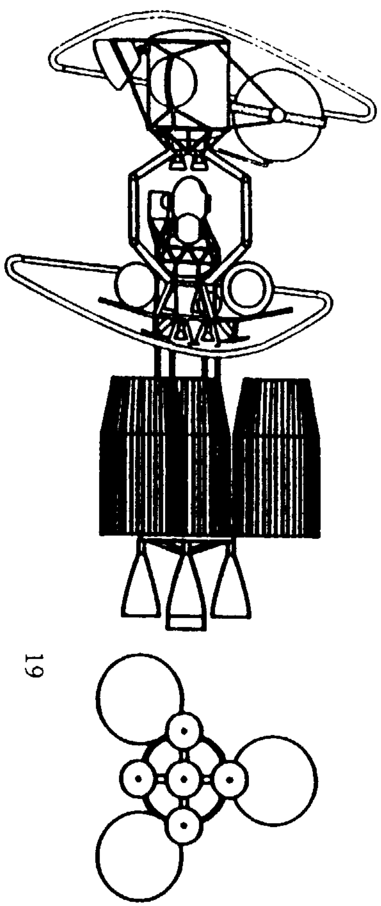


Long Section

5 m

Ascent Vehicle	28.4t
Surface Payload	25.0t
Descent Stage	17.8t
Aerobrake	9.3t
Total MEV	**80.5t**

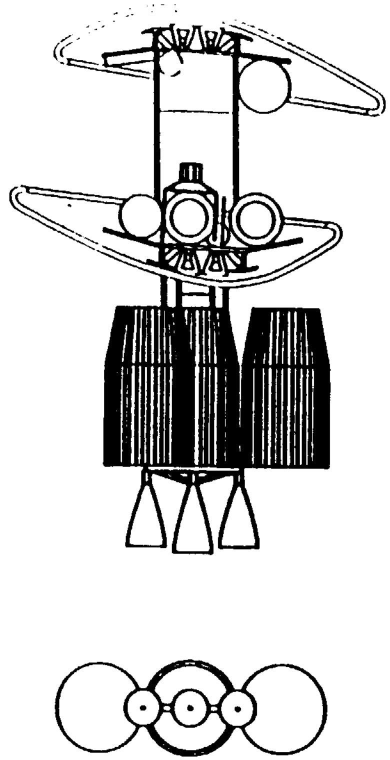




2015 Crew (opposition)

- Reference configuration
- 4 tanksets, 5 engines

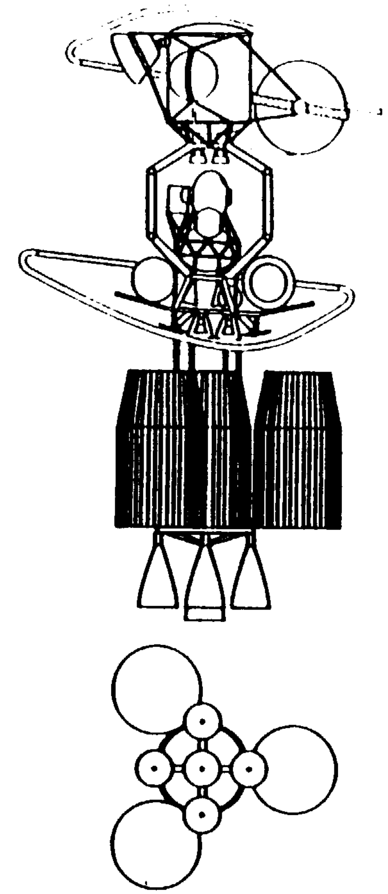
MEV	81
ECCV	8
Crew System	41
TEIS	84
MTV Aerobrake	21
TMIS	539
TOTAL IMLEO	781 t



2017 Cargo

- Reference configuration
- 4 tanksets, 5 engines

MEVs	178
Nav-kit	10
TMIS	412
TOTAL IMEO	581 t



2018 Crew (Conjunction)

- Extra provisions
- 4 tanksets (offloaded), 5 engines

MEV	106
ECCV	8
Crew System	48
TEIS	63
MTV Aerobrake	14
TMIS	437
TOTAL IMLEO	666 t

400

Mars Vehicle , s Statement

(Drop Aeroshell; Earth Return Via ECCV)

2015 MASE Delta V Set: E Dep $\Delta V = 4281$, M dep $\Delta V = 3400$

All masses in kg.

MEV Crew Module	3688
Ascent Stage Inert Mass	3617
Ascent Stage Usable Propellant	20362
Asc RCS propellant	740
Ascent Stage At Liftoff W/O Samples	**28407**
Boiloff	424
Ascent Stage Landed Mass	28831
Landed Surface Cargo	25000
Total Descent Payload	**53831**
Descent Stage Inert Mass	6443
Descent RCS Propellant	2986
Descent Propellant	7977
Lander Aeroshell	9262
Mars Excursion Vehicle (MEV) Gross	**80498**
Mars Transfer Crew Module & Equipment	33291
Consumables	7717
Trans-Earth Injection Stage (TEIS) Inert Mass	10403
Earth Crew Capture Vehicle (ECCV)	7500
Earth Return Cruise Mass	**58911**
TEI Propellant	55455
Inbound Midcourse Maneuver Propellant	1424
TEI Vehicle Departure Mass	**115790**
Mars Capture Aerobrake	20717
MEV Gross	80498
Mars Capture Mass	**217005**
Boiloff	5966
Outbound Midcourse Maneuver Propellant	7245
Comsat (Separation Before Mars Capture)	3000
Interstage Structure	1000
Trans-Mars Injected Mass	**234216**
TMI Stage Inert Mass	55000
TMI Propellant	485410
Initial Mass In Earth Orbit (IMEO)	**774626**

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16. Abstract

A top level assessment is performed of the relative impacts of on-orbit assembly of the lunar or Mars transfer vehicles versus direct launch. The objective of this report is to identify the major option paths for the Earth-to-orbit, ETO, transportation systems. Heavy lift launch vehicles, if large enough, could reduce or eliminate on-orbit assembly. However, with every new approach, there are always counter-balancing considerations and it is the objective of this report to begin the delineation of the necessary follow-on trade study issues.

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